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Energy policy and financing options to achieve solar energy grid penetration targets: Accounting for external costs

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ABSTRACT

This paper presents a review and assessment of public-policy options for supporting large-scale penetration of photovoltaics (PV) in the United States. The goal therein is to reduce the costs both of solar technology and of grid integration, so enabling solar deployment nationwide. In this context, we analyze the solar PV markets and the solar industry globally, and discuss the external benefits of PV that must be advertised, and perhaps marketed, to assure an increase in social support for PV. We discuss existing energy-policy mixes in those countries leading to the development of solar power, highlighting the lessons learnt, and outlining areas of improvement of the existing policy mix in the United States. We highlight that there is a need for a holistic approach including social in addition to economic considerations, and we discuss policy options for supporting the continuation of PV market growth when the current investment tax credits expire.

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1. Introduction

The solar photovoltaics (PV) market grew very rapidly in recent years, mostly driven by technological improvements that reduced costs and government policies supportive of renewable energy. However, solar energy in most places is still more expensive than conventional energy-resources despite rapidly declining costs, and thus, sustained policy support is needed, so that its growth will continue. The right mix of policy towards solar-energy development should arise from the hidden benefits of solar energy, and indeed go beyond the achievement of parity in grid costs. Policy makers′ agenda should include an expansion in the generation of renewable energy and so maintain the reliability of the power grid to address climate change, boost energy-security, develop a domestic industry for green jobs, secure access to electricity in remote areas, and address the external costs of fossil-fired power generation. The need to achieve multiple objectives and gain political- and social-support for the solar industry requires a coordinated effort to come up with the optimal policy mix. The U.S. Department of Energy (DOE) is providing this type of strong coordination through its SunShot Initiative, focusing on direct cost reduction. Launched in 2011, the initiative aims to lower the price of solar-energy systems by about 75% between 2010 and 2020 [1]. Meeting this target is expected to make the unsubsidized cost of solar energy competitive with that of other currently operating energy sources, so paving the way for the rapid, large-scale adoption of solar electricity across the United States. According to the Initiative′s vision study [1], attaining the level of price reductions envisioned in the SunShot Initiative could result in solar energy meeting 14% of U.S. electricity needs by 2030, and 27% by 2050. A more ambitious study shows the feasibility of renewable energy to satisfy 69% of the electricity needs of the U.S. by 2050 [2,3]. The later encompasses the dimension of environmental sustainability in addition to direct cost evaluations. The authors believe that the external benefits of photovoltaics which have driven the early steps of PV technologies development, should be highlighted and monetized, and that continuous attention to environmental, health and safety (EH & S) issues is required for successful commercialization and large scale deployment of PV technologies.

A review of previous studies on political and economic incentives towards renewable energy development revealed that often missing in the literature is the identification of barriers for solar energy development and of clear policy guides to ensure uninterrupted growth in solar deployment after existing policy instrument come to an end. Schmalensee [4] reveals the political appeal of renewable generation and risks involved with major incentive mechanisms. He examined a number of policy features associated with subsidizing the generation of electricity from renewable generation. Schmalensee concluded that in most countries FIT incentives are more popular than RPS policies mainly because this mechanism removes the risk on the investor side. However, he argues that this shifts the risk to other actors without necessarily reducing the risk to the society as a whole. Furthermore, he presented a simple model showing that the long term risk may in fact be lower under an RPS regime than under a FIT regime.

Timilsina et al. [5] covered different applications of FIT and RPS programs throughout the world and identified advantages and disadvantages in specific applications. The authors concluded that although FIT programs help to guarantee a fixed return on investments, they do not help in reducing high up-front costs. Secondly, FIT policies guaranteeing grid interconnection regardless of the location of the project put pressure on transmission infrastructure and electricity rates. Finally, adjustable FIT rates add to the uncertainty for the investors. Frondel et al. [6] harshly criticizes Renewable Energy Sources Act (EEG) in Germany arguing that the FIT scheme failed to achieve its promises on emissions reductions, employment, energy security, or technological innovation while resulting in massive expenditures. The authors argue that government intervention can serve to support renewable energy technologies through other mechanisms such as emission trading schemes and funding for research and development (R & D), which may compensate for under-investment from the private sector. According to their paper, policies investing in R & D in the early stages of development are cost-effective in achieving competitiveness. We are addressing these issues herein, by proposing a mix of different policy tools (‘push’ and ‘pull’ policies together) rather than coming up with a one-fit-all approach as in the German paradigm. Identifying locational potential of solar energy and balancing transmission infrastructures is a key aspect of our policy recommendations. Another critical takeaway from Timilsina et al. [5] is that it emphasizes the importance of loan financing programs at the retail scale level and collaboration between governments and the private sector exemplified by projects in India and China. Along the same lines, Srinivasan [7] studied the optimal subsidy and right incentives for solar energy development in India and concluded that to achieve a significant market share for solar energy comparable to other generation resources, retail solar financing must be flexible.

Certain papers greatly helped with detailing the early experience with RPS and RPS options for solar energy. Wiser et al. [8] summarized some of the early literature regarding efforts to come up with alternative policies to RPS [9]. Wiser also addressed concerns that overreliance on RPS may not support the diversity of renewable resources (e.g., [10,11]). Rowlands [12] expresses concerns that a whole-hearted commitment to RPS could be damaging for the development of renewable energy and devises a

FIT program for Ontario based on the past European experience. Wiser et al. [8], on the other hand, contends that RPS programs can spur the development of solar energy through carve-outs which proved to be more popular and arguably more effective than credit multipliers and enhance diversity of renewable generation. This study successfully identifies cost containment and project financing issues around solar energy development. However, the authors did not present any plans for RPS in the United States nor they tackled the future challenges on the policy and technology sides. Huang et al. [13] and Chandler [14] studied the socioeconomic factors influencing the adoption of RPS in different states in the U.S. These studies relate the adoption of RPS to factors such as gross state product, natural resources and education level and predict the state's choice of adopting or not adopting RPS.

A recent (2013) study by Stein [15] uses a multi-criteria (i.e., financial, technical, environmental and socio-economic) model to rank electric production technologies. He found that wind, solar, hydropower and geothermal provide significantly more overall benefits than biomass, nuclear, natural gas and coal power technologies.

The studies support the premise of our paper that external benefits of solar PV generation and external costs of conventional power generation must be publicized to promote social support, and that socioeconomic factors should be considered to determine the optimal policy mix at the state level.

In the following, we offer policy recommendations based on the current status of the manufacturing industry, trends and barriers in different solar PV markets, and external benefits of solar energy that justify the much needed policy support.

2. Current status of solar power worldwide

2.1. Solar PV markets

Investment in solar PV installations was encouraged recently by substantial falls in the costs of solar PV that resulted largely from its widespread deployment, and lately, by substantial overcapacity/oversupply. Between the first quarter of 2010 and that of 2012, solar PV generating costs fell by 44% [16]. Between 2000 and 2011, global solar-PV capacity increased from 1.5 to 70 GW, viz., an annual average growth rate of 42% (Fig. 1). Around 60% of the market increase happened in Germany and Italy, respectively, with 25 GW and 13 GW of installed capacity at the end of 2011. At the end of 2011, the European Union (EU) accounted for over three-quarters of global solar-PV capacity (51 GW) (Fig. 2). PV represented almost 47% of all new EU electric capacity that came online in 2011 [17].

The increase in solar PV installations in the European Union countries is supported by feed-in-tariffs that considerably reduce a

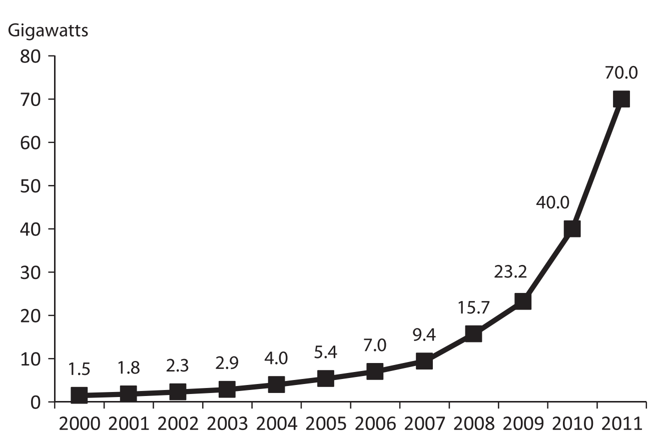


Fig. 1. Solar PV total world capacity (2000–2011).
Source: European Photovoltaic Industry Association [17].

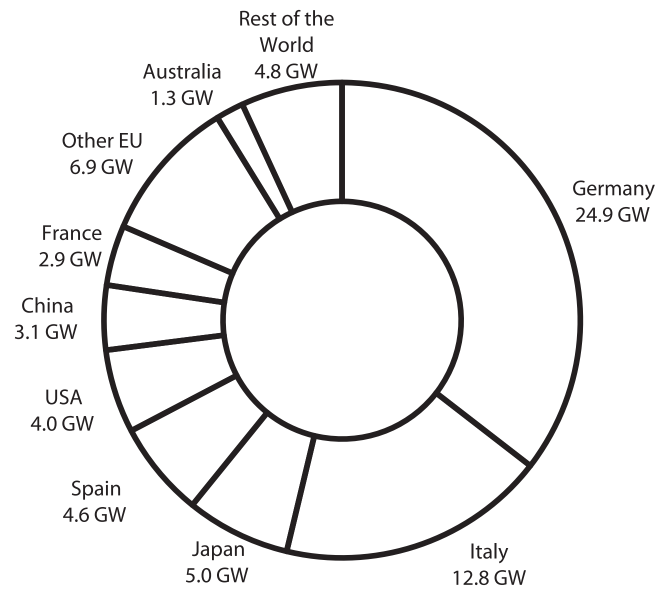


Fig. 2. Solar PV operating capacity in the leading countries, 2011.
Source: European Photovoltaic Industry Association [17].

project's risk as long-term returns are guaranteed, typically for 10–20 years. In some cases, these tariffs were not adjusted quickly enough to reflect the rapidly falling costs of solar PV, and have been too generous. Consequently, the returns offered to the industry were closer to those typically associated with high-risk investments, and led to a massive investment in solar PV installations. In some countries, however, governments responded quickly by reducing feed-in tariffs to levels that better reflected costs [18].

Beyond Europe, the largest PV markets are in China, the United States, Japan, and Australia. Japan continues to rank third globally for total operating capacity. Through 2010, residential systems represented 95% of Japan's solar PV; the share fell to 80% in 2011 with a rise in industrial- and commercial-rooftop systems [19]. In the United States, falling prices combined with state incentives and the extension of federal investment tax credits doubled the market, bringing the total operating capacity to nearly 4 GW by the end of 2011. California (29% of total) remains the nation's largest market, followed by New Jersey (17% of total) and Arizona (15% of total). The market in China rose from eighth to sixth worldwide as it nearly quadrupled in size in 2011, largely in response to the introduction of a national Feed in Tariff (FIT), bringing the total capacity to almost 3.1 GW. Other countries exhibiting notable growth are Canada (364 MW), and India (300 MW) both of which more than doubled their existing capacity in 2011. However, India fell well below its target due to problems with infrastructure, financing, and weather-related delays. There, the vast majority of installed PV capacity today is grid connected, with the off-grid sector accounting for an estimated 2% of global capacity. Yet, particularly in developing countries, there is growing interest in off-grid and mostly small-scale systems.

2.2. Solar PV industry

PV manufacturing capacity has grown rapidly in response to booming global demand, initially in Europe, Japan, and the United States; thereafter, leadership in production shifted to China which expanded its manufacturing capacity massively to meet growing international solar PV demand. In recent years manufacturing capacity expanded much more quickly than demand for PV panels. By 2011, the estimated capacity for solar-cell production was around 20 GW higher than production, and two-thirds higher

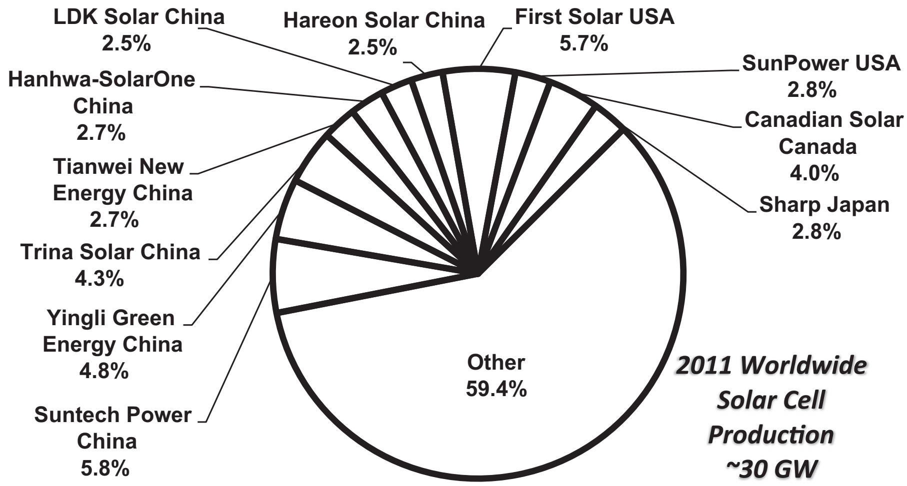


Fig. 3. Market shares of top 11 manufacturers of solar PV modules, 2011. Data. *Source*: Renewable Energy Policy Network for the 21st Century [19].

than the new capacity installed worldwide that year [18]. Since 2008, there also was a sharp fall in the cost of purified silicon, a key ingredient in manufacture. Along with cost reductions from technological advances, these two factors have driven down the cost of PV systems sharply. Worldwide solar-cell production reached 29.5 GW in 2011, with the production of thin films accounting for 11% of the total output. China and Taiwan as accounted for 74% of global cell production. By 2011, 12 of the top 15 manufacturers were located in Asia (Fig. 3). In the United States the production of modules has remains flat over the last years; 32% of the U.S. module production in 2011 was thin-film PV. Although thin film's share of production declined from a high of 21% in 2009 to 13% in 2011, actual production increased to 4.6 GW. Polysilicon output more than doubled between 2008 and 2010 in response to high global prices, with the Si-PV industry accounting for 81% of the demand in 2011 [19].

Module prices fell more than 40% during 2011, while the installed costs of roof-mounted systems dropped by 20% or more [19]. Installers of solar PV systems and electricity consumers have benefited greatly from falling solar PV prices, but solar PV manufacturers around the world, and particularly those in the United States and Europe, experienced financial losses in 2011 and 2012. Cell-, module-, and polysilicon-manufacturers struggled to make profits or even survive amidst excess inventory and falling prices, declining government support, and slower market growth for much of these 2 years. During this period, there was significant industry consolidation worldwide to lower costs and become more competitive; several large companies became bankrupt. Among the U.S.- and European-manufacturing firms that survived, several shifted their production to Asia where labor is cheaper. Trade tensions have arisen between the United States, Europe, and China, resulting in the imposition of import tariffs by the United States in 2012 on solar panels from China [18].

Many solar PV manufacturing firms continued their vertical integration by expanding into project development to remain competitive. Large companies developed new business models and partnered with electric utilities, real estate developers, sports teams, and retailers. Others have become involved in direct retailing, installations, and after-sale service.

3. Hidden benefits of solar energy

The U.S. government recently underwent scrutiny for subsidizing renewable projects through its loan warrantee program and other policy instruments. We believe that a better job can be done by explaining the rationale for supporting the development of solar energy. We believe that the justification for such support would be greatly amplified by explaining the several other invaluable benefits of solar energy, an often neglected competitive dimension. We do this below.

3.1. Climate change

Insurance against the risks of climate change induced by emissions of greenhouse gases, is a strong argument for subsidizing renewable-energy generation.

Carbon Capturing and Sequestration (CCS) technologies have not proven economically viable so far in reducing or eliminating CO_2 emissions from fossil-fired electricity generation [3]. CCS costs are high, and also there is a penalty in energy production of 25–40% when a CCS is installed on coal plants. Besides, carbon storage on vast scales carries environmental risks. CO_2 is stored in deep geological formations, or in the form of mineral carbonates. Deep ocean storage no longer is considered feasible because it greatly increases the problem of acidifying the oceans. Geological formations currently are deemed the most promising sequestration sites [20]; nevertheless, there is the risk that CO_2 might leak with time from the storage into the atmosphere. Release of highly concentrated CO_2 is toxic to plants, animals, and humans. Another risk with carbon storage is it can cause acidification of aquifers, leaving heavy metals in the ground water.

Nuclear energy, which does not emit any greenhouse gases during its operation, has its own problems. After the Fukushima disaster, the safety of nuclear energy again is being questioned. Germany stated that it will close its 17 nuclear reactors by 2022 [21]. In the United States, NRG Energy cancelled its South Texas Project (1700 MW) in Bay City, TX due to concerns with nuclear safety following the Fukushima disaster and uncertainties with projects costs and financing. New York Governor Cumo is determined to shut down Indian Point nuclear plant that is within 50 miles of New York City [22]. In addition, Scana Energy and Constellation Energy cancelled two separate nuclear power plant projects for similar reasons during their application process for DOE's nuclear loan guarantee program. The storage of nuclear waste is another major concern with nuclear energy. Since consideration for Yucca Mountain nuclear repository project was abandoned some years ago, the United States does not have any long-term plan for storing high-level radioactive waste, currently stored on-site at various nuclear facilities around the country [23].

Improvements with hydraulic fracturing and horizontal drilling technologies in the past two decades has paved the way for the commercialization of shale gas and emergence of natural gas as the dominant fuel for power generation in the United States. Sustained low natural-gas prices economically favor the efficient natural gas combined-cycle generation against that of conventional coal-fired power. Besides, several lobby groups promote natural gas as the clean energy alternative because its emission of several different gases and particulate matter is low relative to other fossil fuels [24]. Compared to the average air emissions from coal-fired power plants during, generation of energy from natural gas life-cycles may generate half as much carbon dioxide, less than a third as much nitrogen oxides, and only one percent sulfur oxides compared with the power plant. However, in terms of climate change, even emitting half as much carbon dioxide as coal does not reverse the effects of climate change especially considering the growing energy needs in developing countries. Also, there are studies pointing to the likehood of accidental methane releases in hydraulic fracturing of shale gas that could cause total GHG emissions to rise significantly [25]. Similarly, methane can be emitted as the result of leaks and losses during transportation [26]. There are proposals for applying carbon sequestration to natural-gas-fired generation. However, this will not take care of the fugitive- and accidental-releases of methane that has a Global Warming Potential (GWP) 21 times higher than that of CO_2 over a 100-year period, and 72 times higher over a 20-year horizon [27].

Hence, this leaves renewable energy (i.e., solar, wind, hydro and geothermal) as the leading economically viable and environmentally sound option to reduce CO_2 emissions in line with the Kyoto Protocol while meeting the growing energy needs of the world until technological and safety breakthroughs with other low emission technologies (nuclear, CCS) are achieved.

3.2. Energy security and diversification

For many countries in the world, subsidizing renewables on the basis of energy security is justified. The United States is not among these countries given that North American is self-sufficient in energy resources, especially in natural gas, and coal; furthermore, only about 2% of U.S. oil is used to generate electricity [4]. However, lack of diversification of the U.S. mix of power generation is an issue for the future. Between 2003 and 2011, two-thirds of new power-generation capacity built was natural-gas-fired power [28], and we face the risk of relying too much on natural gas for power generation in the next 10–20 years. Given the cyclical nature of natural-gas prices, 20 years from now, the volatility of electric prices may become an instability driver in the U.S. economy.

3.3. "Green" and high tech jobs

The notion of 'Green Jobs' was one of the main pillars of President Obama's 2012 Election Campaign. The idea is that subsidies for renewable electricity generation will change the composition of domestic employment and ensure that high-skilled, high-value-added jobs will boost the income per capita. Wei et al. [29] estimated jobs gains in renewable energy and consequential job losses in the coal and gas industries in the U.S. and determined that all non-fossil fuel technologies create more jobs per unit energy than coal and natural gas. More specifically, solar-PV is estimated to create 0.97 job-years per GWh vs. only 0.11 for coal, oil and gas [15]. Counterpoints were made against this notion, such as arguing that it is unlikely that the most efficient way to create jobs in an environment of recession would be to subsidize switching from one capital-intensive method of generating electricity to another, and furthermore, suggesting that a large domestic market does not guarantee healthy domestic industry [4]. However, history shows that nations with technological niches generate the highest income per capita, and, consequently, renewable energy revolution can be the way that the U.S. can regain its technological dominance.

3.4. Access to electricity

In the last century, electricity has become a major driver of economic activity. Having a reliable power grid is the building stone of improved healthcare, access to knowledge and efficient manufacturing in today's world.

Unlike many other power-generation technologies, photovoltaics do not always require a wholesale electricity infrastructure. Especially in the underdeveloped countries where a power grid has not been developed by the government or the private sector, solar energy maybe critical in improving the access of people to electricity. Such availability of power is a fundamental economic element in improving the economics of such countries.

Even in developed countries, having rooftop solar systems on the demand side reduces the need for transmission- and distribution-system upgrades and can improve reliability significantly. In the United States most of the power outages are caused by problems in transmission and distribution networks; this was also experienced during the Hurricane Sandy [30]. Flooding and fallen trees caused power blackouts in large parts of NY and NJ. About 90% of Long Island, NY lost power and it took from 30 hours to 18 days for the power to be restored [30]. Although precautionary measures were taken, ground level power generators and substations were affected. At the same time, according to multiple sources, most of the photovoltaic systems were left untouched by the storm [30]. From information gathered in the U.S. and Japan, adherence to the building codes when installing a roof-top PV system has been sufficient in preserving the system. Individual roof-top PV installations will be affected if the roofs are damaged by from fallen trees or gusty winds stronger than what the building codes account for, however, the storm damage on the distribution grid would cause failures to multiple demand points. Thus, meeting a portion of the electricity load through adequately installed rooftop PV can reduce the number of outages and hence lower economic losses in the future.

3.5. Full accounting of electricity costs

Recognizing the significance of the external costs of energy, the U.S. Congress requested a study in the Energy Policy Act of 2005 and later directed the Department of the Treasury to fund it under the Consolidated Appropriations Act of 2008. The National Research Council (NRC) formed a committee to carry out the study, and was asked to define and evaluate key external costs and benefits, viz., those related to health, environment, security, and infrastructure that are associated with the production, distribution, and use of energy but are not reflected in market prices or fully addressed by current government policy. Estimates of damages from air pollution in this study were based on emissions of non-greenhouse gases, such as SO_2, NO_x, $PM_{2.5}$, and PM_{10} and included the impacts on human health, yields of grain crops and timber, building materials, recreation, and visibility of outdoor vistas. Health damages, which include premature mortality and morbidity, constituted the vast majority of monetized damages, with the former being the single largest health-damage category [31]. This study examined information on burdens, effects, and damages associated with electricity generation from coal, natural gas, nuclear power, wind energy, solar energy, and biomass. It encompassed the life-cycles of fuel exploration, extraction, processing and its transportation to power-generation facilities

(upstream externalities), as well as electricity generation and distribution (downstream externalities). The external costs were estimated to range from 1 to 15 cent/kWh depending on the mining location and age and type of the power plant (Fig. 4). The external costs of photovoltaics, enacted by the use of fuels in their life-cycles, were estimated to be ~0.2 cents/kWh for operation under average Southern European irradiation. When the air pollution damages quantified by the study are added to levelized costs of new base-load sources, coal is not an attractive option. Even without including the damages related to climate change, adding the external costs associated with the coal-fired generation of electricity make its costs higher than that of wind- and solar-generation.

The multi-criteria model employed by Stein [15] assigns much higher values to wind, solar, hydro and geothermal than in biomass, nuclear, coal, oil and gas. The model assigns the highest socio-economic-political ranking to solar-PV, and the highest financial return and environmental ranking to wind; the external costs assigned to PV and wind were 0.60 and 0.19 EU cent/kWh correspondingly. However, the source of this estimate was the ExternE project, which used 1990 PV data corresponding to early and less efficient PV installations in Germany.

Using detailed life-cycle inventory data from 11 European and U.S. PV companies in 2004–2005, Fthenakis and Alsema [32] determined the external costs of PV for South European installations to be in the range of 0.126–0.177 EU cent/kWh, thus slightly lower than those of wind. We would therefore recommend the use of these more recent figures for estimating the external costs of PV.

Epstein et al. [33] estimated that the total external costs of coal-fired electricity during extraction, transport, processing, and combustion are $345 billion or 18 cents per kWh of electricity produced, so tripling the price of electricity from coal in the United States. Even if a fraction of such external costs were included in the bids of the energy suppliers, economically, solar energy would compete with fossil-fired generation. The Environmental Protection Agency (EPA) has taken steps to factor in the external costs of conventional power generation and limit emissions of power plants through environmental regulations, viz., the Mercury and Air Toxics Standards (MATS), the Cross-State Air Pollution Rule (CSAPR), and New Source Performance Standards (NSPS) under the Clean Air Act Section 111. The EPA also released an on-line and database and map showing the major greenhouse gas emitters in the U.S. This is expected to increase societal pressure for power plants to reduce atmospheric emissions [34].

What is beyond the EPA's jurisdiction is that renewable power generation are given clean-energy credits. However, States or the Federal Government could offer monetary incentives to investing in reducing the real costs of electricity by fully accounting for them. This can be done by adding or subtracting external costs to utility process. Keske at el. [34] describes a market-based solution for adding external costs to new generation sources or power generation expansions in the state of Colorado. The proposed policy will impose a "shadow price" upon the new sourcing emissions and the utilities are required to evaluate alternatives on the basis of total social cost, equal to the bid price plus the appropriate adder. Under this proposed policy, generators with low operating costs are still financially rewarded. However, financial incentives are also offered to generators for accomplishing environmental emission and performance targets [34]. This approach can be integrated into a hybrid model that considers a full-value-based feed in tariff (FIT). In addition to the environmental costs, there are opportunity costs of foregone value for not using renewable energy; these costs include but are not limited to value for avoided generation capacity, value for avoided T & D capacity upgrades, value for grid support services, value for

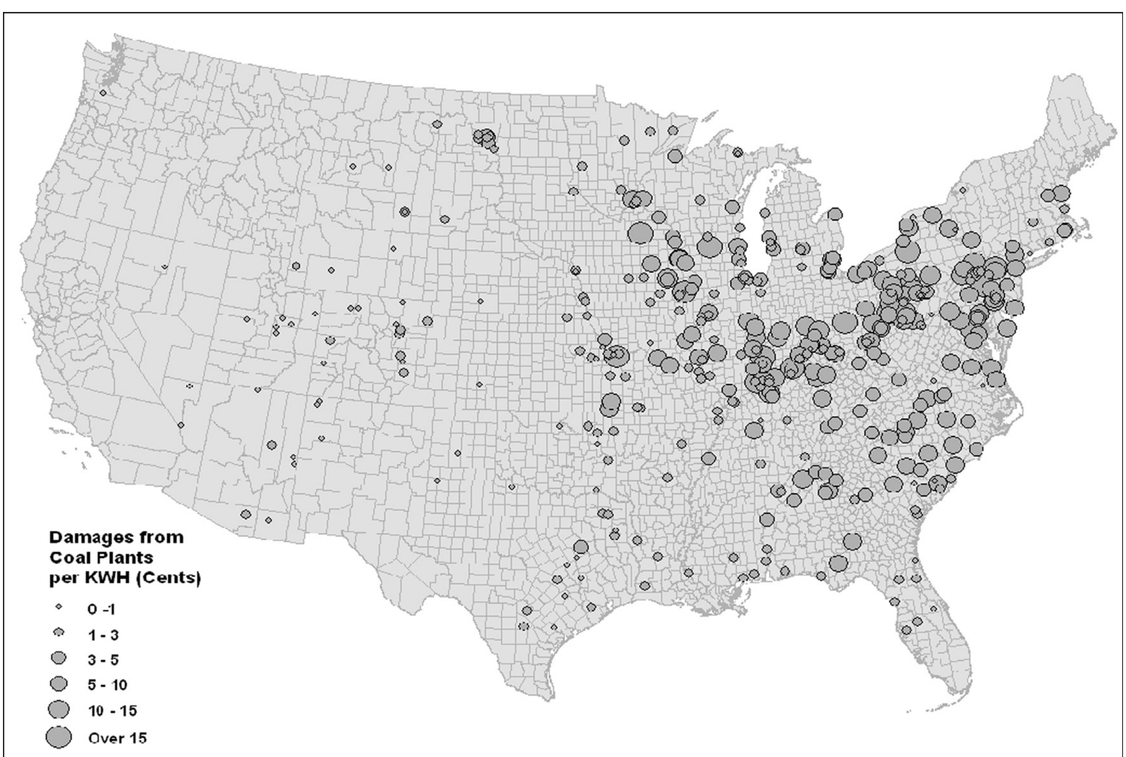


Fig. 4. Regional distribution of air-pollution damages from coal generation in 2005); damages related to climate change are not included.
Source: National Research Council [31].

financial fuel price hedging, and value of preserving finite fossil-fuel resources [35].

The external costs of conventional energy sources should be used as a basis for any credits or subsidies for renewable-power generation.

4. Policies towards solar energy worldwide

At the wholesale level, the leveled cost of solar energy is not on par with conventional energy commodities. At the retail level, distributed solar can be competitive in states with high retail electricity rates and good solar irradiation (e.g., California). However, to a large extent, solar energy has to rely on some form of subsidy to be compatible with conventional energy sources, at least over the short-term. Recently, state- and local-policymakers have shown increasing interest in spurring the development of customer-sited solar photovoltaic markets [36].

The policies used to support solar energy across the World typically are grouped as "pull" and "push" policies [37]. The former create a strong demand for solar power by incentivizing solar deployment, whereas the latter policies create a supply of solar power by incentivizing manufacturing and/or Research and Development (R & D). A successful policy mix usually should encompass combinations of the two, so to further the development of a self-sufficient, continuously improving solar industry. Otherwise, such industry would have to rely on imports or exports for sustained growth. For instance, in Europe the dominant "pull" policies created a demand for solar power. However, lack of sustained "push" policies prevented solar manufacturing industry from having major breakthroughs. In contrast, On the other hand, in China dominant "push" policies expanded know-how and allowed cost cutting in the industry. However, Chinese solar PV manufacturers rely mostly on exports for market growth. Given the reduction of subsidies for solar in Europe and the United States, Chinese solar PV manufacturers face the risk of a shrinking solar PV market, and consequently, excess solar PV panels in their inventories.

4.1. Policy instruments

The strong growth in solar PV markets has been driven by the sustained implementation of policy instruments. Before making recommendations for an optimum policy mix towards assuring the development of solar energy, the existing policies should be examined.

4.1.1. Feed-in-tariffs (FITs)

FITs refer to a tariff or a power-purchase agreement to new renewable energy technologies which are relatively near a premium price compared to conventional technologies for generating electricity. The tariff is based on the cost of the electricity plus some reasonable return for the investor. FITs are implemented in more than 75 jurisdictions including EU countries, Australia, Brazil, Canada, China, and in California [5]. The FIT especially has played a major role in boosting solar energy in Germany and Italy.

4.1.2. Tax credits and rebates

Different variations of tax credits have been implemented in several countries. These credits are in the form of percentages of capital investments made, such as Investment Tax Credits (ITCs), or in the form of dollars per each unit of electricity generation as are the Production Tax Credits (PTCs). Whatever the form of the credit, the idea is to reduce the levelized cost of solar electricity to be on par with that of other forms of electricity generation. The 30% ITCs especially significantly leveraged the development of solar energy in the United States.

Despite their instrumental role in promoting solar energy, the proponents of conventional energy resources often criticize the ITCs for placing additional burdens on the budgets of the countries. However, ITC programs can generate positive returns for the governments in the forms of direct payroll taxes and other revenues. An analysis by the U.S. Partnership for Renewable Energy Finance [38] demonstrates that, over the lifetime of the solar assets, leases and PPA-financing structures can deliver a nominal 10% internal rate of return (IRR) to the federal government on the federal investment tax credit (ITC) for residential- and commercial-solar projects. Accordingly, a $10,500 residential solar credit can deliver a $22,882 nominal benefit to the government, while a $300,000 commercial solar credit can create a $677,627 nominal benefit in lease and PPA scenarios over 30 years. These government returns are generated by the direct participants in a solar transaction, i.e., the developer (or an investment fund established by the developer), the system installer, and the energy user. The U.S. PREF website gives the financial models of this payback analysis.[1]

Furthermore, contributions paid to solar-energy developers can be in different forms of rebates. For instance, the rebate program for solar PV in California under the California Solar Initiative (CSI) aims to support 3 GW of Solar PV in there by 2017 using rebates, also known as 'buy-down' or 'performance-based-incentives'. For systems 50 kW or smaller, the buy-down level is calculated from the system's expected performance, taking into account tilt, location and orientation. The subsidy is referred to as 'expected-performance-based buy-down'.

4.1.3. Carbon taxes/programs

The primary goal of charging for carbon emissions is to reduce greenhouse-gas emissions causing global warming. Solar PV generation benefits indirectly from incremental carbon costs as the fossil-fuel power generation that PV displaces emits high volumes of CO_2. Natural gas-fired generation in the United States has an average CO_2 emission rate of 516 kg/MWh; in contrast, coal-fired generation has an average CO_2 emission rate of 1022 kg/MWh [39]. Assuming the low end in future estimates of incremental CO_2 costs, $20 per metric ton would increase the levelized cost of electricity from coal-fired generation by 2 cent/kWh, and it raises leveled cost of electricity from natural gas-fired generation by 1 cent/kWh.

California's greenhouse gas (GHG) cap-and-trade program is a central element of California′s Global Warming Solutions Act, and covers major sources of GHG emissions in the state, such as refineries, power plants, industrial facilities, and transportation fuels. The regulation includes an enforceable GHG cap that will decline over time. The California Air Resources Board (CARB) will distribute allowances, i.e., tradable permits, equal to the emission allowed under the cap. CARB held its first auction of greenhouse gas allowances (GHG) on November 14, 2012; it included a Current Auction of 2013 vintage allowances and an Advance Auction of 2015 vintage allowances. The settlement price for 2013 carbon allowances cleared at $10.09/ton [40]. Seemingly, in the current regime of regulations the carbon taxes imposed do not fully account for the external costs of carbon emissions.

4.1.4. Renewable Portfolio Standards

In the Renewable Portfolio Standard (RPS) programs, renewable energy production or consumption targets are set and the electricity suppliers (utilities or the load-serving entities) are obliged

[1] http://www.uspref.org/images/docs/SC_ITC-Payback_July_12_2012.pdf.

to meet those targets or pay Alternative Compliance Payments (ACPs). Most of the time, the suppliers are required to meet a certain portion of their retail electricity sales through renewable energy. In some cases, there are installed capacity targets for renewable generation (e.g., the Texas market). The RPS programs create a trading regime wherein utilities with low achievements in renewable energy can buy from those with levels above their requirements.

Renewable Portfolio Standards (RPS) especially has emerged as a popular form of policy in the United States; 31 out of the 50 states have some form of RPS programs (Fig. 5). The standards range from 10% to 40%. New Jersey became the first state to create a carve-out in its RPS program for solar energy. This system has created a stand-alone market for Solar Renewable Energy Credits (SRECs), whose market price was capped at $300/MWh. In New Jersey, 4.1% of retail sales should be generated from in state solar facilities by 2028 [50]. As of March 2013, 17 states have RPS programs with solar- and/or distributed generation-carve outs [51].

Quota obligation schemes based on tradable green certicates (TGCs) have become a popular policy instrument in the Nordic countries and Poland. Also, in 2011, India launched a new REC scheme that is linked to its existing quota policies.

4.1.5. Financing options/loan guarantees

The project financing of solar projects has been proven challenging given the relatively high costs (both for utility solar and rooftop solar) of solar projects, the uncertain life cycle for solar panels, and the lack of business models for financing in the private sector.

Several governments have loan-financing programs available for solar-energy projects. In India, Shell Foundation worked with two investment banks to develop renewable-energy financing portfolios. This project helped the banks put in place an interest rate subsidy, marketing support, and a vendor qualification process. Within two and a half years, these programs had financed nearly 16,000 solar home systems [5].

In the United States, the Energy Policy Act of 2005 [41] authorized the Department of Energy (DOE) to issue loan guarantees for projects that "…avoid, reduce or sequester air pollutants or anthropogenic emissions of greenhouse gases; and employ new or significantly improved technologies as compared to commercial technologies in service in the United States at the time the guarantee is issued." The current loans for energy efficiency, renewable energy, and advanced transmission and distribution projects under the Loan Programs Office adds up to to $32.4 billion as of October 2013 [42].

4.1.6. Public investment

One of the main drivers of solar energy development in developing countries is public investment. Many developing countries (e.g., China, India) host several government- and donor-funded projects to support solar energy under their rural electrification programs.

4.2. Policies in selected countries

By 2012, at least 109 countries had some type of renewable energy policy [19]. More than half of them are developing countries or emerging economies. Of all the policy instruments that were detailed in the earlier section, feed-in-tariffs and renewable portfolio standards are the commonest. We make recommendations towards developing solar policies, based on our review of those in different countries and later, in Section 6, offer an assessment of future trends in solar energy.

4.2.1. United States

United States has a combination of “pull” and “push” policies towards developing solar energy, some of which were discussed previously. Among various state- and federal-level incentives, perhaps the most effective one is the Federal ITC for solar PV projects that is equal to 30% of expenditures on any equipment that employs solar energy to generate electricity. In addition to ITCs, the U.S. Federal Government also assures an additional cost recovery through accelerated depreciation schedules. Solar energy projects qualify for a 5-year depreciation. The projects that were completed by 2011 used to get 50% bonus depreciation in the first year because of the Economic Stimulus Act of 2008. However, the new solar projects will not get this bonus depreciation unless another Act is passed. The DOE’s Loan Guarantee program is a good example of push policy incentives, which supports the

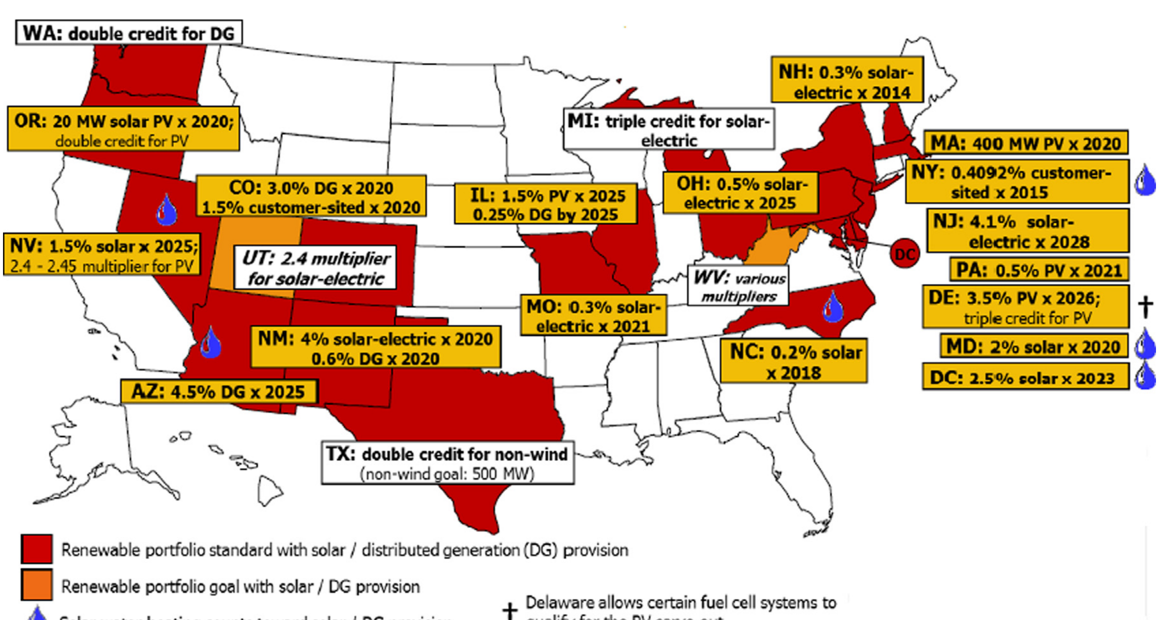


Fig. 5. Set-asides and multipliers for solar energy in the United States.
Source: DSIRE [51].

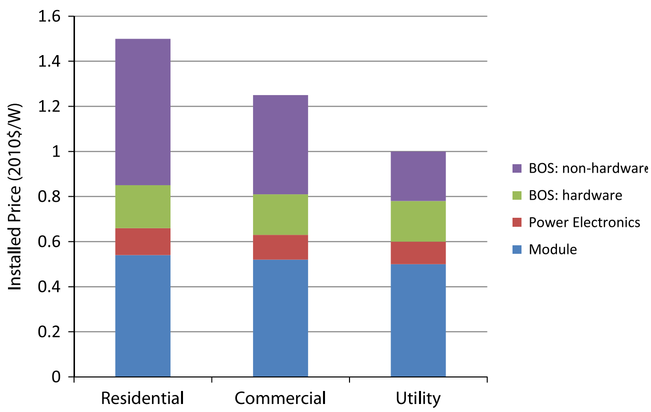


Fig. 6. Estimated subsystem prices to achieve 2020 SunShot targets.
Source: NREL [1].

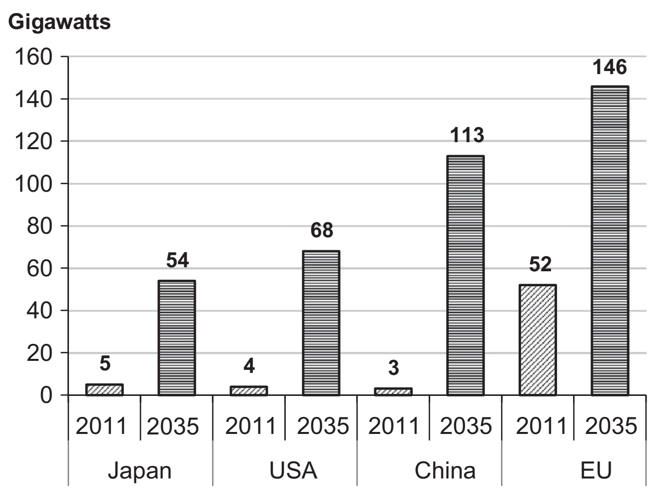


Fig. 7. Projected growth in solar PV installed capacities in IEA's new policies scenario.
Source: International Energy Agency [18].

manufacturing side of the industry. Increased R & D support also is designed to sustain a technological advantage that is a prerequisite for the continuation of PV evolution.

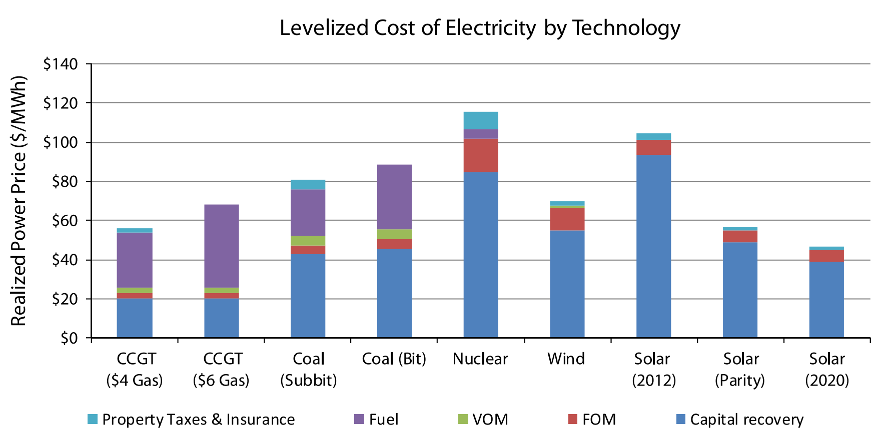
4.2.2. Germany

In 2000, the German government introduced a large-scale feed-in-tariff system under the 'German renewable Energy Sources Act' (EEG). It resulted in explosive growth of solar PV deployment. By 2011, Germany was producing 14% of its energy from renewable sources that has been attributed to the success of its comprehensive FIT system [43]. German FIT payments are technology-specific, such that each renewable-energy technology type receives a payment based on its generation cost, plus a reasonable profit. Each tariff is eligible for a 20-year fixed price payment for every kWh of electricity produced. Germany's FIT assessment technique is based on a so-called corridor mechanism. This mechanism sets a corridor for the growth of PV capacity installation that is dependent on the PV capacity installed the year before; this results in a decrease or an increase of the FIT rates according, respectively, to the percentage that the corridor path is exceeded or unmet. As PV capacity installations were above those planned by government in 2010, the FIT rates were decreased by 13% on January 1, 2011.

Germany's generous FIT system has been criticized for not producing the desired results in accord with its total costs of nearly $30 billion euros between 2000 and 2010 [44]. In its report on German energy policy, the IEA suggests that 'policies funding R & D activities can be more effective in promoting PV than the very high feed-in tariffs, on the ground that 'the government should always keep cost-effectiveness as a critical component when deciding between policies and measures'. The absence of German PV manufacturers from the list of top solar PV companies (Fig. 1) and the share of German companies in the global solar PV manufacturing sector denote that Germany worked mostly as a "pull" market during the last decade.

4.2.3. China

The rapid development of the PV industry and market in China primarily reflects governmental support. Programs for rural electrification were the driving force for expansion of the solar PV



Cost Item ($/MWh)	CCGT ($4 Gas)	CCGT ($6 Gas)	Coal (Subbit)	Coal (Bit)	Nuclear	Wind	Solar (2012)	Solar (Parity)	Solar (2020)
Capital recovery	$20	$20	$43	$46	$85	$55	$94	$49	$39
FOM	$3	$3	$5	$5	$17	$11	$8	$6	$6
VOM	$3	$3	$5	$5	$0	$1	$0	$0	$0
Fuel	$28	$42	$24	$33	$5	$0	$0	$0	$0
Property Taxes & Insurance	$2	$0	$5	$0	$9	$2	$3	$2	$1
Total	**$56**	**$68**	**$81**	**$89**	**$116**	**$70**	**$104**	**$57**	**$46**

Notes: In the Solar (Parity) levelized cost example, grid parity with CCGT technology is achieved at $1500/kW installed cost with 25% capacity factor. Solar (2020) assumes $1200/kW installed cost for solar PV by 2020 as in McKinsey's Analysis and 30% capacity factor.

Fig. 8. Results of the LCOE analysis.

market in China in the last two decades. Most PV projects were government sponsored with international aid, or within the framework of government programs at the national or local levels. China's energy policy is developed through a two-step approach. The central government first sets up broad policy goals in its Five Year Plans. Ministries, agencies, and the National People's Congress then use those plans to design specific- and targeted-programs and policies [45].

The major supporting programs are the Brightness Program Pilot Project, the Township Electrification Programs, and the China Renewable Energy Development Project [5]. The plans in the Brightness Program Pilot Project, launched in 2000, will provide electricity to 23 million people in remote areas by 2010, using 2300 MW of energy from wind-, solar PV-, wind/PV hybrid- and wind/PV/diesel hybrid-systems. The Township Electrification Programs, launched in 2002, installed 268 small hydro stations and 721 PV-, PV/wind hybrid-systems by 2005. The China Renewable Energy Development Project (REDP), also established in 2002 and supported by a World Bank's Global Environmental Facility (GEF) grant, afforded a direct subsidy of $1.5 per W to PV companies to help them market, sell, and maintain 10 MW of PV systems in Qinghai, Gansu, Inner Mongolia, Xinjiang, Tibet, and Sichuan [5].

4.2.4. Japan

Japan was the worldwide market leader in installed solar generation capacity until the end of 2004 [46] despite its scarcity of wide open fields suitable for installing large-scale PV systems and relatively low solar irradiance throughout the year. That success was driven by long-term Japanese PV research and development programs, as well as market implementation that started in 1994.

In 2008, the Japanese Government announced an 'Action Plan for Achieving a Low-carbon Society' that targets increasing by 10-fold the installations of solar power generation systems by 2020, and 40-fold by 2030 [43]. That same year, 'Action Plan for Promoting the Introduction of Solar Power Generation' announced measures to support the development of solar technology and promote installation of solar in selected sectors [37]. As directed by these action plans, the Ministry of Economy Trade and Industry (METI) announced its FITs policy in July 2010, which took effect in 2012. Under this FITs scheme, if a renewable energy producer requests an electric utility to sign a contract to purchase electricity at a fixed price and for a long-term period guaranteed by the government, the electric utility is obligated to accept this request. In the 2012 FITs scheme, solar PV generation was given a 42 yen/kWh fixed price ($\approx$ 50 cents/kWh) of 20 years for projects greater than 10 kW, and of 10 years for projects smaller than 10 kW [47]. The high tariff rates of solar energy mostly are necessitated by the low solar irradiance and are justified by the high costs of imported natural gas and oil in Japan.

Since the surplus electricity purchase system that allows customers to sell their excess solar electricity back to the power grid was established in 2009, the introduction of residential photovoltaic power generation largely increased in Japan.

4.2.5. India

In India, the primary policy driver is all-in FITs of around 15 cents/kWh for solar PV and thermal projects commissioned after March 2011 for up to 25 years. Solar PV projects in remote locations even receive higher subsidies. One such program that aims to establish a-single light solar PV systems in all non-electrified villages covers 90% of costs of projects. For below-poverty-level families, state governments underwrite 100% of the system costs [5].

5. Future trends in solar photovoltaics

The solar industry is entering a period of balancing supply and demand that is likely to set the conditions for more stable, expansive growth over the long term. Difficulties in the solar PV industry are likely to persist in the short term, while the imbalance between supply and demand endures. How quickly the balance is restored depends largely on the rate of growth of demand for solar PV. Developing countries, especially China, represent a large potential market, but its demand for solar PV in the short term is uncertain. Solar PV costs are expected to decline, although at lower rates as the oversupply situation is corrected.

The McKinsey analysis [48] suggests that the cost of a commercial-scale rooftop system could be reduced by 40% by 2015, to $1700/kW, and another 30% by 2020 to nearly $1200/kW, a value that corresponds with the SunShot Initiative targets (Fig. 6). Such costs would enable solar power to compete with natural-gas-fired power generation, even in a projected low-price environment. The price of natural gas price in the United States, currently around $4/MMBtu,[2] is not sustainable as going forward the cheaper shale resources will be depleted, production gradually will shift to less productive and more expensive resources, and demand from the industrial- and power-sectors will rise. Projecting that natural gas prices range from $4/MMBtu to $6/MMBtu in the next 10 years [62], new solar projects must reach a Levelized Cost of Electricity (LCOE) of $55–$70/MWh or $1500/kW capital cost with a ~20% to ~25% capacity factor to compete with newly built conventional generation resources at the utility (wholesale) level, assuming that the current solar ITC program will remain in place (Fig. 8).[3] Reaching this cost threshold will take time in the absence of subsidy programs, but the use of solar generation as an alternative to the conventional modes will be achieved in the longer term. In the shorter term, solar PV growth will be attained in the residential- and commercial-retail segments. Several factors will govern the growth of residential- and commercial-solar PV, such as the availability of low-cost financing, acquisition costs per customer, and reactions from regulated utilities (for instance how utilities will charge customers for transmission- and distribution-costs).

Although some underlying trends are difficult to shift, government policies strongly influence energy markets. In its 2012 Renewable Energy Outlook, the International Energy Agency (IEA) reported several projections of solar-PV generation and installed capacities in different government-policy scenarios. IEA's business as usual (BAU) scenario, 'New Policies Scenario' takes into account existing policy commitments and assumes that those recently announced are implemented. This scenario affords a baseline that shows how energy markets would evolve if underlying trends in energy demand and supply do not change. In the New Policies Scenario, the global electricity generation from solar PV in 2035 is over 26-fold that of 2010, increasing from 32 TWh to 846 TWh. Its share in total generation rises to just over 2% in 2035. Installed solar PV capacity increases from 67 GW in 2011 to over 600 GW in 2035, due to continuing cost reductions and government support. This expansion is in line with the recent growth of global solar-PV capacity.

Over the Outlook period, EU capacity increases to some 146 GW, accounting for 5% of its electricity generation in 2035 (up from 1% in 2010). In the United States, capacity increases from 4 GW in 2011 to 68 GW in 2035. Other countries with large amounts of solar PV capacity in 2035 are China (113 GW), India (85 GW), and Japan (54 GW) (Fig. 7).

[2] Henry Hub Spot Delivery as of 5/17/2013 was $3.89/MMBtu.

[3] Levelized Cost of Electricity (LCOE) analysis by the authors is included in Appendix A.

The McKinsey Analysis [48] suggests that installed Solar PV capacity worldwide will increase to between 400 and 600 GW by 2020. At this level of demand, annual capacity additions are expected to rise from 26 GW in 2011, to 77 to 100 GW by 2020. According to this analysis, growth is likely to continue in the residential- and commercial-solar PV segments in the United States potentially reaching a tipping point in 2015 that could enable unsubsidized demand for Solar PV to grow between 200- and 700 GW by 2020. Demand is likely to be concentrated in 10 states. Indeed, 50% of the available power delivered to the residential and commercial segments in some of these states may be generated by solar PV by 2020.

Finally, trade disputes between countries will shape global future trends in Solar PV manufacturing. Various governments, such those of India and Canada, already enforced a domestic-content mandate to prevent subsidies flowing towards imported technologies. In November 2011, the U.S. Department of Commerce (DOC) initiated investigations of anti-dumping (AD) and countervailing duty (CVD) of imports of solar cells from China. In October 2012, the final determination indicated the DOC's intention to impose duties on U.S. imports from Chinese solar PV manufacturers based on their subsidy rates.[4] This decision in U.S. was a harbinger of a protective trend in the solar-PV manufacturing industry and what is to come in Europe. In May 2013, The European Commission agreed to impose punitive import duties on solar panels from Chinese manufacturers. This decision had a major impact on Chinese solar PV manufacturers given that Europe is the world's largest market for solar panels, which accounted for 7% of China's total exports to the EU in 2011.[5]

6. Policy Recommendations for growth of solar energy

The growth of solar PV industry will be driven by a multi-year sustained policy mix that guarantees attractive returns on solar PV investments and addresses the technical- and regulatory-requirements for solar energy. In the United States, this mix comprises federal ITCs, loan guarantees, RPS, and renewable energy certificates (REC). Below we outline potential improvements of the existing policy mix in the United States, and propose an alternative policy mix should the Federal ITC program does not get the political support it needs to be extended beyond 2016.

6.1. Areas for improvement in the U.S. policy mix

The existing policy mix in the United States can be deemed successful by looking at the recent increase in solar PV deployment throughout the country. However, when trends in the solar PV industry are analyzed further, it becomes evident that there are issues with market stability and some gaps in the existing policy mix hindering the further deployment of solar PV. The needed improvements in the mix include R & D funding, solar financing flexibility, markets for clean energy credits, a nationwide program on greenhouse gas emissions, permitting costs, and planning for end-of-life recycling.

6.1.1. R & D funding

Research and Development (R & D) is the backbone of efforts to reduce the costs and improve the reliability of solar energy. Establishing long-term roadmaps and maintaining core competence in R & D centers are essential to the PV industry's competitive advantage. The stability and continuity of R & D funding is as important as is market stability to the success of a renewable energy policy. The cost of solar energy can be reduced via bettering efficiency and reliability/life expectancy. Newer technologies may necessitate more R & D support after they pass a sustainability test. For instance, in recent years, thin film technologies, such as CdTe, lowered their costs to levels below those of the incumbent crystalline-Si technology. However, the research on thin-film technologies is relatively immature and there is much to be done in enhancing efficiencies and lowering costs with these technologies. Another research area that is critical for the future of solar energy is improving storage technologies. With the goal of controlling the ramp rates of solar PV generation, such research encompasses characterizing PV variability, modeling battery physics, and optimizing dispatch via energy-storage units. These steps require an interdisciplinary systems approach between engineering, physics, and chemistry.

In China, the government subsidizes the solar-manufacturing companies to the extent that has led to international trade disputes. However, Europe and the United States still retains the technological edge and has the highest number of licenses with the second-generation thin film technologies. The EU has been funding Research and Development projects with Research Framework Programs (RFPs) since 1980 [43]. The EU's R & D activities are organized under RFPs and are closely linked to EU funds. Many research institutions, covering from basic material research to optimizing industry processes are supported under RFPs. In the United States, the DOE's SunShot Photovoltaic Manufacturing Initiative (PVMI) has invested $110 million in 5 years in manufacturing-focused research projects that strengthen the competitiveness of the U.S. PV module industry and supply chain, with the objective of reducing cost of solar energy by 75% [49]. In addition the Sunshot program supports research in reducing the administrative costs of PV deployment which, due to multiple local and state permitting rules are much greater than in other countries with active PV support programs; for example administrative/permitting costs in Germany account for ~7 cents per W, whereas in the U.S. as of 2011 they accounted for ~$1/W [50].

The DOE also has a larger scale loan guarantee program for innovative technologies; however, the DOE's loan guarantees are small relative to those in China.

The private sector is likely to under-invest in R & D given the risk of knowledge spillover when intellectual property rights are not protected, and the returns on investments are unpredictable [37]. Therefore, the U.S. government should subsidize R & D activities in the solar industry in the form of government-sponsored laboratories, or direct funding to the private sector. Furthermore, the government has the responsibility of safeguarding and improving public health and the environment, and, therefore continuing funding is needed for proactive research on the EH & S impacts of new technologies and large-scales of deployment. An example of a successful paradigm of government support to EH & S is funding for Sematech of which 10% was allocated by statute to R & D on EH & S impacts and pollution control.

6.1.2. Solar financing flexibility

To achieve a significant market share for solar energy comparable to other generation sources, retail financing must be flexible [7]. Innovations in solar financing and business development are critical for the growth of solar energy.

At the utility scale, merchant solar projects are considered as financially risky projects as the generation output of solar panels over the long-term are uncertain, and also the dispatch profile of

[4] http://trade.gov/press/press-releases/2012/final-determinations-in-the-anti dumping-duty-and-countervailing-duty-investigations-of-imports-of-solar-cells-from-china-101012.asp.

[5] http://online.wsj.com/article/SB10001424127887324125504578509302593743088.html.

solar generation varies, both of which increase the expense of financing solar projects. Long-term power purchase contracts with all-in prices lower the risk of utility scale solar projects by reducing the revenue uncertainty over the project's lifetime. However, at the residential level, there is no option of signing a contract with the utilities or states.

In the United States, solar projects historically were financed by energy- sector players, banks, and the federal government; however, this pattern is rapidly changing [51]. Recently, new business models are emerging for residential solar systems that emphasize third-party financing. Companies like SunCap Financial and Clean Power Finance provide 20-year financing plans for installing rooftop solar panels. Therefore, customers need to pay monthly loan payments for their rooftop solar rather than monthly electricity bills. That business model is convenient and its economics work in some states.

New business models are introduced in the energy sector where solar panels are seen as investment vehicles with reasonable returns over time. Energy sector players develop business models between utility scale systems and rooftop solar ones (e.g., neighborhood small-scale solar fields, so maximizing total returns by increasing the system's capacity factor (by receiving higher irradiance compared to rooftop solar ones), while minimizing transmission, distribution, and storage needs. Cooperation with power generator utilities enables the transmission utilities to allocate fields for developing neighborhood solar farms, taking into consideration the transmission infrastructure. In return, the generators of power can get a guarantee that customers installing solar PV panels will not be required to pay transmission- and distribution-charges. Eliminating uncertainty about whether customers have to pay such charges in the future would remove one of the barriers for the growth of residential solar energy systems.

In the utility scale, flexibility in solar financing is achieved through the support of long-term contracts given by utilities and enforced by renewable- or solar-targets. In the residential and commercial retail solar segment, cooperation of power generators with transmission utilities and the introduction of new business models reducing the acquisition and financing costs of customers, will determine the pervasiveness of solar PV.

6.1.3. Greenhouse Gas programs

Greenhouse Gas (GHG) emission programs with carbon taxes per tons of CO_2 emissions (or carbon credits for zero-emission technologies) help to levelize the cost of solar power such as it will be in par with fossil-fired power generation. While negotiations continue towards an international treaty with binding targets, it is important that individual jurisdictions move forward with their greenhouse-gas programs. In the United States, several efforts to reduce CO_2 emissions from existing assets so far have failed. However, the Environmental Protection Agency (EPA) released a new rule in 2012 to regulate CO_2 emissions from power plants that effectively would ban the operation of new coal power plants without Carbon Capture and Sequestration (CCS) technologies.[6] Once America has its national CO_2 emission targets in place, solar PV projects will get a major boost to their growth as they reach parity with the grid cost faster. Indeed, if EPA's efforts on a national CO_2 program fail, a new regulatory policy with carbon credits for zero-emission technologies (rather than carbon taxes on fossil-fired generation) will be necessary to sustain political and social support in accounting for the external costs of fossil-fuel life cycles.

[6] http://www2.epa.gov/carbon-pollution-standards/2013-proposed-carbon-pollution-standard-new-power-plants.

6.1.4. Markets for solar energy credits

With today's low natural-gas price market, a separate budget for solar energy is a necessity, reflecting the maturity and the potential of solar PV technologies in terms of resource availability and proximity to load pockets. As discussed in Section 4.1.4, only 17 State RPS programs have provisions for solar- or distributed-generation provisions [52]. Furthermore, only in a handful of states these solar targets are sufficiently aggressive to boost the number of projects.

Solar Renewable Energy Credit (SREC) markets, pervasive in the Northeast U.S., usually do not provide a long-term price guarantee for solar projects. The scarcity of such long-term SGreen jobsREC contracts makes project investments a highly risky bet; furthermore, the boom-bust cycles, whereby build rates are well ahead of regulators' expectations, create instances of massive SREC oversupply [51]. New Jersey is an example of a SREC market that currently is flooded with oversupply. During 2010 and the first half of 2011, in the monthly auctions, New Jersey SREC prices cleared at above $600/REC (MWh). However, in 2012, as the state reached its Solar RPS targets, SREC prices crashed to below the $100/MWh level [52]. Recently, the New Jersey Board of Public Utilities (BPU) began investigating ways to lessen the volatility of solar development as required by the Solar Act of 2012. Various means are suitable for strengthening SREC prices, the most straightforward being lifting or accelerating the targets for solar carve-outs. Legislatures in New Jersey and Pennsylvania already are evaluating proposals to accelerate SREC targets. However, accelerating SREC targets would not reduce volatility of SREC prices in the long-term. Generators need long-term SREC contracts so to lower the risks with their solar investments.

In most SREC markets, 3- to 5-year forward contracts are available, so reducing price fluctuations for power generators. However, 3- to 5-year price guarantees are usually not sufficient to obtain financing for solar PV projects. Legislatures should focus on mandating the availability of long-term (10-year or 15-year) contracts. These sometimes are not easily compatible with load-serving arrangements in deregulated markets, but, in some cases, have been implemented through creative workarounds. Connecticut, for example, recently introduced a solar carve-out program, which requires electric distribution companies to allocate funds towards procuring SRECs, which will be delivered in standard, 15-year contracts [53]. Following Connecticut's example, states can lessen the variability in developing the solar market.

6.1.5. Recycling programs

Recycling spent modules may not be seen as an immediate issue with developing solar energy. However, the rapid growth of solar energy eventually will result in problems of waste disposal within 20–30 years. Even today, there are environmental concerns about the impacts from uncontrolled disposal of PV. PV recycling will resolve them, and will create secondary sources of materials that will benefit the environment. Recycling can provide a significant secondary source of materials that may be used in producing future PV systems. All three metrics of the sustainability (i.e., low cost, resource availability. and lowest impact to environment) could be addressed through recycling of spent modules [54]. The cost of solar energy is impacted by the price of material inputs such as polysilicon, tellurium, steel, and glass. Their prices are driven by the status of their supply and demand. The shortage of polysilicon between 2005 and 2008 caused the prices to spike to $500/kg. Following that, massive investments in new capacities in the industry led to an oversupply in 2009, thereby reducing spot prices to $55/kg [37]. Recycling helps to avoid shortages of such materials needed for PV production and lowers the cost of PV modules. Currently recycling programs are established for only

Table 1
Assumptions for the LCOE analysis.

A. General assumptions									
Tax rate	37.6%								
Property taxes	1.5%								
Insurance	0.3%								
COD year	2017								
Base cost year	2013								
Capital/O & M Cost escalation	2.25%								
Discount rate for tax attributes	9.0%								
	CCGT ($4 Gas)	**CCGT ($6 Gas)**	**Coal (Subbit)**	**Coal (Bit)**	**Nuclear**	**Wind**	**Solar (2013)**	**Solar (Parity)**	**Solar (2020)**
B. Technology assumptions (2013 $)									
Overnight capital cost ($/kW)	1000	1000	3000	3000	6000	1900	2300	1500	1200
Useful life (yr)	30	30	50	50	60	25	25	25	25
Heat Rate (MMBtu/MWh)	7.0	7.0	9.5	9.5	10.0	0.0	0.0	0.0	0.0
VOM ($/MWh)	2.50	2.50	4.25	4.25	0.00	1.00	0.00	0.00	0.00
FOM ($/kW-yr)	16	16	30	30	120	36	12	12	12
Tax life (yr)	20	20	20	20	15	5	5	5	5
Tax Depr shelter (%)	18	18	18	18	21	30	30	30	30
PTC flag (1=Yes, 0=No)	0	0	0	0	1	0	0	0	0
ITC shelter (%)	0	0	0	0	12	0	30	30	30
Capacity factor (%)	65	65	85	80	90	35	20	25	25
Fuel price ($/MMBtu)	4.64	6.0	3.0	3.5	0.5	0.0	0.0	0.0	0.0

two types of PV modules: CdTe and c-Si. The first recovers glass and the semiconductor elements for reuse in CdTe synthesis, whereas the second only recovers the aluminum frame and the glass. PV recycling of mature technologies (e.g., c-Si and CdTe) is technically and economically feasible [55]. Accounting for secondary production from recycling and the continuing improvements of module efficiencies and material utilization, a number of studies show that the availability of tellurium in the forthcoming decades is sufficient for a cumulative production at the TW level [54–58]. In Europe, the PV industry established PVCYCLE, a voluntary program to recycle PV modules (www.pvcycle.org). This type of industry-wide approach to economically manage large-scale recycling should become an essential component of cost reduction roadmaps.

6.2. Alternative policy mix beyond 2016

The federal ITC program in the United States has been a key driver in the increase of solar PV deployment. In 2008, the Senate reached a bipartisan agreement to extend federal solar-tax credits till the end of 2016, and also to improve the credit program so to eliminate the cap for residential solar systems, and allow the electric utilities to use of commercial credits that improved the PV economics.[7] The multiple-year extension of the residential- and commercial-solar ITC helped annual solar installation grow by over 1600% since the ITC was implemented in 2006 – a compound annual growth rate of 76%.[8] However, investment tax credits will be reduced from 30% to 10% after 2016 unless legislative actions are taken to extend these credits. Alternatives should be in place in case the solar ITC program does not get bipartisan support, a prerequisite for extending the program beyond the President′s 4-year tenure, and would be phased out. In such a case, the solar PV industry may face a major setback in 2017 as levelized cost of solar energy would not have reached parity with the grid cost in most states without further incentives, despite the rapidly dropping costs of solar systems.[9] As the solar ITC program eventually is phased out, adjustable feed-in tariffs can be proposed as an alternative mechanism to incentivize the deployment of solar PV technologies. Given the experience with state-level REC and SREC programs in the United States, and the states having jurisdictions over renewable targets, such an incentive mechanism can eliminate the need for a bipartisan support for a long-term term incentive program towards developing solar energy.

6.2.1. Adjustable Feed-in Tariffs

FITs played a major role in promoting solar energy in European countries, such as Germany and Italy. Guaranteed payments over a period of years offer investors sufficient confidence to fund the initial capital in solar projects. However, the challenge with FIT designs mostly is that it can over- or under- compensate solar projects as there is no market pricing mechanism in many programs. As the costs of feed-in-tariffs usually are passed on to consumers, it is essential to design incentives that attract sufficient investment while yet permitting adjustment of subsidies for new additions to capacity as technology costs fall, so avoiding unnecessary increases in electricity prices and maintaining public acceptance. In this sense, Germany′s FIT program is a good starting point in terms of adjusting the FIT prices based on previous year′s figures for solar PV installation. Still, modifications need to be made with the German FIT program before it can be implemented viably in the United States. Thus, U.S. FIT programs can be built upon experience with state-level REC markets. The size of contract payments for solar projects can be determined based on a SREC supply/demand dynamic rather than a pricing corridor mechanism as in Germany. The differences of the proposed U.S. FIT program from existing SREC markets would be the following: (1) It will be at the national level; (2) adherence to compliance requirements will be designated to the electric-distribution companies requiring them to allocate funds for 10-year contracts similar to the Connecticut example; and, (3) allocations to electric distribution companies will be based on historical solar irradiance data, so encouraging solar development in states that have the highest potential for efficiency and dispatch.

Finally, FIT programs by themselves do not encourage innovations and improvements in solar PV manufacturing. It should be noted that “push” side policy instruments (such as R & D support, loan guarantees) should be sustained even with the existing policy mix or the new policy mix beyond 2017.

[7] http://www.seia.org/news/senate-reaches-bipartisan-agreement-extend-improve-solar-tax-credits.

[8] http://www.seia.org/policy/finance-tax/solar-investment-tax-credit.

[9] http://www.greentechmedia.com/articles/read/What-Happens-When-the-ITC-Expires.

7. Discussion and conclusion

Solar energy is a viable alternative to fossil-fuel based energy generation for addressing the climate change, meeting growing energy needs, and replacing aging power infrastructure in the United States. Solar in a mixture of alternative clean energy generation [59,60] can replace the current power infrastructure of the United States. However, solar energy technologies still are evolving and in most areas their costs are higher than the costs of conventional energy sources. We identified potential road blocks for solar energy development in the U.S. in the near future. We show that there is a need for a holistic approach including social and environmental, in addition to economic, considerations, and we discuss policy options for supporting the continuation of PV market growth when the current investment tax credits expire.

Considerations of social experience and regulatory framework can justify implementing public policies options towards developing solar energy. Different examples of successful policies in the world towards this solar-energy goal share a common trait; such policy instruments are implemented through long-term incentive programs. In that sense, U.S. policy makers need to develop the right policy mix for promoting solar energy, while sustaining social- and political-support for it. To ensure sustained growth especially beyond 2017 when ITC program for solar projects is scheduled to expire, investors should be given a variety of incentives for increasing the use of solar energy, such as long-term power contracts, low-cost financing options, incentives for research and development, and credits for displacing CO_2 and toxic emissions in power generation. Part of the full accounting of energy costs lies in the economic determination of externalities so that they are defined, managed, and regulated.

Solar PV should be one of the key components of transition strategy to a world with stabilized atmospheric CO_2 which has increased by 30% since 1950 [61]. The U.S. has incentives to be the leading country in this trend. PV has accomplished great cost reductions and this trend will continue during the current decade; most importantly, PV does not involve the safety and environmental issues that the other alternative energy resources possess. Besides, investing in solar PV technologies expand the green tech space in the country and eventually help to eliminate the external costs of fossil fuels. High capital expenditure requirements and safety issues with CCS and nuclear reactors prevent power producers or financial players from investing into such technologies unless revolutionary technological breakthroughs are achieved. Natural gas is considered as an economically viable option and relatively more reliable form of energy. However, natural gas would cut the GHG emissions by less than half compared to coal fired generation and it does not offer a long term solution. Considering the growth in energy needs globally, long term solutions to decarbonize the energy world should be put forward immediately, not a decade or a couple of decades later.

The technically available potential of solar energy is far in excess of our energy needs and solar with wind and other renewable resources of energy can provide most of our energy needs. However, serious investment in solar energy need to continue to sustain the current trend of cost reductions and grid penetration. Only with a sustained policy mix covering all the levels of solar industry, we can see solar energy being the dominant energy source of the 21st Century and source of manufacturing revival in the United States. Governments can and should justify incentives given to the solar industry by communicating the external costs of conventional-generation sources and the hidden benefits of solar energy.

Additional studies on Solar Renewable Energy Credit (SREC) structures and the relationship between social, environmental and economic factors influencing the adoption of RPS in different states in the U.S. would promote the acceptance of photovoltaics energy in the society.

Appendix A. Levelized cost of wholesale electricity

The traditional approach for comparing the cost of generating electricity from different technologies relies on the “levelized cost” method. The levelized cost (LCOE) of a power plant is calculated as follows:

$$LCOE = CR + PTI + O\&M + FC$$

And

$$CR = \frac{OCC}{CF \times 8760} \times \frac{WACC(1+WACC)^t}{(1+WACC)^t - 1}$$

where *CR* is the capital recovery, *OCC* is the overnight capital cost (net of ITC for solar), *O & M* is the annualized operating and maintenance expenses (variable and fixed), *PTI* is the annualized property taxes and insurance, *FC* is the annualized fuel costs, *CF* is the capacity factor of the plant, *WACC* is the weighted average cost of capital and *t* is the economic life of the plan.

Data sources include EIA [62] and Brattle Energy group for capital cost and O & M assumptions of coal steam and NGCC and nuclear technologies, Sunora Energy and GE Capital for assumptions of solar and wind technologies. Fuel costs are in line with the authors' long term price expectations for natural gas and coal. Capital cost and capacity factor scenarios for solar PV are produced in line with McKinsey's analysis; these are shown in Table 1.

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